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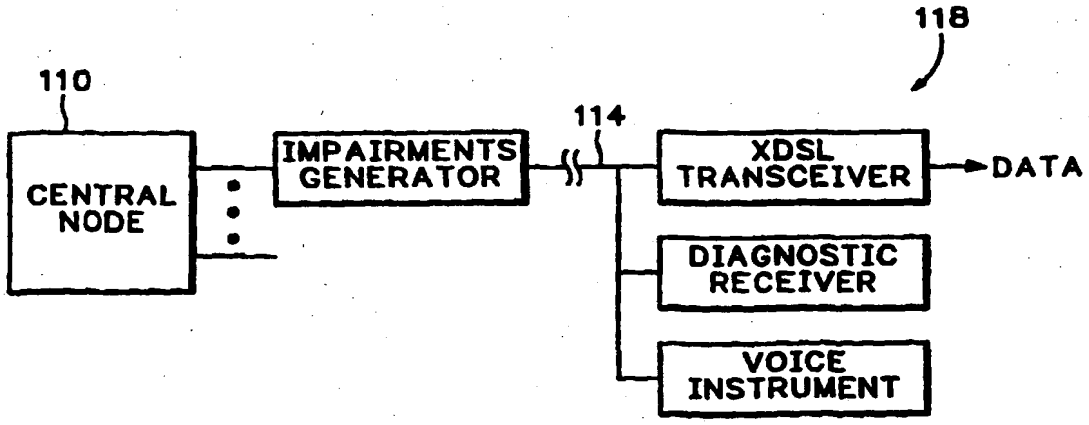

(57) Abstract

Digital data in error protected packets is used to modulate a carrier and the modulated carrier is impressed on a digital data distribution network for transmission to a receiver over a transmission path. In order to monitor operation of the data distribution network, the transmission path is impaired to a selected extent upstream of a transmission path segment that is to be tested and an error protected data packet is transmitted over the transmission path to the receiver. A determination is made at the receiver whether the received data packet is error free, and, if not, a message is transmitted from the receiver to the transmitter.

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METHOD OF OPERATING A DIGITAL DATA DISTRIBUTION NETWORK

Background of the Invention

This invention relates to method of operating a digital data distribution network.

In a conventional cable television system, a video information signal in analog form, such as the NTSC composite video signal, is employed to modulate the RF carrier of an assigned RF transmission frequency channel at the system headend and the RF signal is distributed over a cable network to multiple subscriber nodes. At a subscriber node there may be a cable-ready television receiver including a tuner which can select the frequency channel and a detector which recovers the video information signal from the selected channel and employs it to control operation of the television display.

A data distribution system in which the information signal is transmitted in digital form has well known advantages over a system in which the information signal is transmitted in analog form. Accordingly, it has been proposed by the United States Federal Communications Commission (FCC) that terrestrial transmission systems under the jurisdiction of the FCC should phase out use of the NTSC composite video signal by 2007 and should instead use digital video information signals to modulate RF carriers. The digital video information signal provided by a video signal source will then be composed of a succession of bits segregated into digital data packets. The data packets modulate an RF carrier which is broadcast from the transmitter. Each period of the RF carrier conveys several bits of the digital information signal in one symbol. For example, in the 64QAM modulation scheme, each symbol conveys six bits of the digital information signal. The television receiver selects the frequency channel, detects an analog information signal, converts the detected information signal to digital form and recovers the digital data packets. The

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digital information signal is then used to control operation of the television display.

The change in standards from analog to digital for terrestrial television transmission effectively dictates that cable television systems will also have to provide digital video signals in order for the video signals to be compatible with digital television receivers.

Referring to FIG. 1, a digital cable television system includes a digital processing interface 8 which receives a digital video information signal, such as the MPEG transport stream, and generates an error protected digital signal composed of a succession of error protected digital signal packets. The error protected digital signal is applied to a modulator 10 which employs it to modulate an RF carrier which is typically in the frequency range 50-550 MHz, although it may be higher or lower. The digitally modulated RF carrier is supplied to a transmitter 14 which impresses the signal on a propagation medium 16. In the case of a cable television system, the propagation medium is a network of coaxial cables configured as a trunk extending from the transmitter 14 and having numerous branches connected to the trunk by directional couplers 18, sub-branches connected to the branches by directional couplers, and so on, and connected at the subscriber nodes to digital television receivers 20.

Each receiver 20 has a front end 22 including a tuner (not shown) which converts the RF signal to intermediate frequency and an analog-to-digital converter (ADC) 26 which digitizes the IF signal and provides a digital output signal to a demodulator 30. The demodulator 30 removes the IF component and provides a digital output signal, which, ideally, should match the error protected digital signal provided to the modulator 10. The receiver front end 22 also includes a digital processing circuit 32 which carries out the inverse of the error protection algorithm employed at the headend and ideally provides at its output a digital video information signal which matches the signal supplied to the digital processing interface 8. The digital video

information signal from the digital processing circuit 32 is supplied through a decoder (not shown) which the MPEG transport stream and supplies an analog video signal to display circuitry 34 to control operation of the television display.

Error protection is employed in the digital cable television system to allow correction of bit errors, i.e. incorrect values of digital 1 or digital 0, in the output signal of the demodulator 30 caused by impairments in the transmission path from the input of the modulator 10 to the output of the demodulator 30.

Provided that the bit error rate is below a critical value, known as the critical bit error rate and generally considered to be about 10^{-4} for a digital television signal, digital error correction techniques can correct the errors and provide a signal having a bit error rate that may be less than 10^{-11}, which is sometimes referred to as quasi-error free. The maximum bit error rate that can be tolerated is considered to be about 10^{-3} before error correction.

Some video signals in a cable system are transmitted in encrypted form in order to restrict their use to subscribers who have paid an additional fee, either on a periodic basis for premium channels or on a pay-per-view basis for particular programs. In this case, the digital processing interface 8 not only applies a digital error protection algorithm but also encrypts the digital video information signal, so that the digital data packets provided to the modulator 10 are error protected and encrypted. In order to decrypt the digital data packets and regenerate the analog video signal, the subscriber is provided with a set top terminal 40 which is connected between the cable system connection and the display circuitry 34, by-passing the front end 22. The set top terminal includes a tuner (not shown) an ADC 42, a demodulator 44 and a digital processing circuit 46, performing the same general functions as the front end 22, but the digital processing circuit 46 performs not only error correction to recreate the digital signal applied to the

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modulator 10 but also decryption in order to extract the digital video information signal supplied to the digital processing interface 8. It is expected that much of the programming distributed by digital transmission cable systems will be transmitted in encrypted form, so that a subscriber will need a set top terminal, or equivalent functionality built into the television receiver, in order to display a variety of programming.

The economic value of a cable television distribution system resides in its ability to distribute video payload, i.e. the program material that subscribers wish to view, to a large number of subscribers without excessive degradation. The system operator derives revenue based on the system's ability to distribute the video payload. Accordingly, it is important that the system operator be warned of impairments in the distribution system, so that these impairments can be corrected before they adversely affect the ability of the system to distribute video payload and hence the revenue derived by the system operator. The operator must therefore be able to measure impairments in transmission quality so that appropriate repairs can be made. Typical impairments that should be detected and repaired are reductions in signal-to-noise ratio (SNR), e.g. due to noise being coupled into the transmission channel, reductions in frequency response, reductions in phase response, phase noise, jitter, addition of interfering signals and addition of multipath signals.

Hitherto, it has been suggested that the bit error rate of an RF digital transmission system may be a satisfactory measure of transmission channel quality, but this measure is subject to disadvantage because an RF data distribution system in which the information signal is digital is subject to the "cliff effect," in that the curve that relates bit error rate to the quality of the transmission channel, expressed as signal-to-noise ratio, has a very steep drop off. Thus, referring to FIG. 2, a change of less than 1.5 dB in signal-to-noise ratio can cause the bit error rate to

change from less than 10^{-4} to more than 10^{-3}. The curves shown in FIG. 2 assume that the only impairment is noise when in fact there will always be other impairments, which can make the drop off even steeper. Accordingly, the system operator is not alerted to impairment of the transmission quality of the channel either by BER measurements or by a relatively small increase in subscriber complaints. On the contrary, the operator may not learn of an impairment until the system fails. This makes it difficult to monitor the noise margin in the system, to track degradations and fix degradations before a system failure.

In a report issued by the European Telecommunications Standards Institute (ETR 290: May 1997), it is suggested that the estimated noise margin is a better indicator of transmission channel quality than bit error rate. The estimated noise margin is based on the probability of mathematically added noise causing a bit error and is approximately the difference between the current estimated signal-to-noise ratio and the estimated signal-to-noise ratio at which the bit error rate exceeds the critical bit error rate. Use of the estimated noise margin to identify impairments is subject to disadvantage because it is computationally expensive and is not applicable to impairments other than noise. Further, its reliability is limited because there is an unknown set of errors associated with calculating the estimated noise margin. Since the estimated noise margin is not the same as the actual noise margin, there is a possibility that the current signal-to-noise ratio is substantially less than the estimated signal-to-noise ratio, and consequently the actual noise margin may be substantially less than the estimated noise margin. It would therefore be desirable to determine the actual noise margin of the transmission channel.

Summary of the Invention

In accordance with a first aspect of the invention there is provided a method of operating a digital data distribution

network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising (a) generating an error protected data packet for transmission over the transmission path, (b) impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested, (c) transmitting the data packet over the transmission path, (d) receiving the data packet at the receiver, and (e) determining whether the received data packet is error free.

In accordance with a second aspect of the invention there is provided a method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising (a) generating an error protected data packet for transmission over the transmission path, (b) transmitting the data packet over the transmission path as an analog signal, (c) receiving the analog signal at the receiver, (d) recording the analog signal received at the receiver, and (e) transmitting the record of the analog signal to a remote location for analysis.

In accordance with a third aspect of the invention there is provided a method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising generating an error protected data packet for transmission over the transmission path, impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested, transmitting

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the data packet over the transmission path, receiving the data packet at the receiver, and counting bit errors in the received data packet.

In accordance with a fourth aspect of the invention there is provided a method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate a carrier and impressing the modulated carrier on the network, said method comprising (a) generating an error protected data packet for transmission over the transmission path, (b) impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested, (c) transmitting the data packet over the transmission path as an analog signal, and (d) receiving the analog signal at the receiver.

Brief Description of the Drawings

For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which

FIG. 1 is a partial schematic block diagram of a proposed form of cable television system,

FIG. 2 is a graph illustrating bit error rate as a function of signal-to-noise ratio in a digital data communication system.

FIG. 3 is a partial schematic block diagram of the headend and receiver in a cable television system embodying the present invention,

FIG. 4 is a map of part of a cable television system, and

FIG. 5 is a partial schematic block diagram of a digital subscriber line system.

Detailed Description

A first application of the invention will be described with reference to a digital cable television system.

The cable TV system shown in FIGS. 3 and 4 is used to distribute digital video information signals from a headend 48 to subscriber nodes 50. Referring to FIG. 3, the headend 48 includes a digital processing interface 8, a modulator 10 and a transmitter 14 similar to the corresponding elements shown in FIG. 1. The digital processing interface receives the MPEG 2 transport stream and performs various operations, including energy dispersal, error protection, interleaving and base band shaping in order to generate inphase and quadrature signals which are applied to the modulator 10. All the functions of the digital processing interface, and possibly also the functions of the modulator, may be performed in a single integrated circuit. In addition, the headend 48 includes an impairments generator 60. The impairments generator 60 may be located between the transmitter 14 and the cable network 16, as shown in FIG. 3, or it may be incorporated in the digital processing interface 8 or the modulator 10. The effect of the impairments generator 60 is to degrade to a selectively controllable extent the quality of the transmission path between the digital processing interface 8 and the subscriber nodes 50. The impairments generator may function by adding noise to the transmission channel or degrading the frequency response or phase response of the transmission channel. Further, the impairments generator may introduce "spurs" (spurious modulation products) and phase noise or jitter. The manner in which the impairments can be applied to the transmission channel is well known to those skilled in the art. Considering, for example, the signal-to-noise ratio, the quality of the channel may be degraded at the headend using an impairments generator that couples noise into the transmission channel. The extent to which the signal-to-noise ratio is degraded depends on the amplitude of the noise.

As shown in FIG. 4, the cable network 16 includes a trunk extending from the headend 48. Branches and sub-branches are connected to the trunk by directional couplers 18. Each subscriber node 50 is at the end of a branch or sub-branch. The cable system operator maintains a map of the cable network, showing schematically the topology of the path to each subscriber node 50. At each active subscriber node 50, there is a diagnostic cable receiver 64 (FIG. 3) connected between the cable network and the display circuitry 34 of the subscriber's digital television receiver. The cable receiver 64 may be implemented as a set top terminal or it may be housed in the same cabinet as the digital television receiver. Each cable receiver has a unique ID and the cable system operator maintains a database relating cable receiver IDs with the subscriber nodes and billing addresses. If the database also relates the cable receiver IDs with physical addresses, the system operator is able to determine not only the physical location of each cable receiver but also the topology of the path between the headend and each cable receiver.

Referring to FIG. 3, the cable receiver 64 includes a tuner (not shown) for converting the received signal to the intermediate frequency, an ADC 66, a demodulator 68, a digital processing circuit 70 and a decoder (not shown), similarly to the set top terminal 40 described with reference to FIG. 1. A controller 74 included in the cable receiver controls operation of the other components of the cable receiver 64.

The capabilities of the digital processing circuit 70 are expanded relative to those of the digital processing circuit 46. The digital processing circuit 70 has a video data output for supplying the MPEG transport stream to the decoder, which supplies an analog video signal to the display circuitry 34 of the digital television receiver. The digital processing circuit 70 includes an error bits counter which accumulates the number of error bits in the received signal. The error bits counter can be queried by the controller 74

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and reset from time to time, so that the controller is able to calculate the bit error rate based on the error bit count and the time that has elapsed since the counter was reset. The controller 74 supplies a digital data word representing the calculated value of the bit error rate to a digital processing interface 76, which produces an error protected data packet.

The cable receiver 64 also includes a memory 80 which can be enabled to store the output signal of the ADC 66 during a selected interval. The stored digital signal is applied to the digital processing interface 76 to generate an error protected data packet. The error protected data packet produced by the digital processing circuit 76, either from the bit error rate word or from the signal provided by the memory 80, is supplied to a modulator 82. The modulator 82 uses the error protected data packet to modulate an RF carrier, typically at a frequency in the range 5-50 MHz, although it may be higher or lower. The modulated RF signal is applied to a transmitter 84 which impresses the signal on the cable network.

The headend 48 of the cable system also includes a receiver 90 for receiving the return messages provided by the transmitter 84 in each of the cable receivers 64. The receiver 90 includes a tuner (not shown), an ADC 92 which digitizes the return message signal, a demodulator 94 which removes the IF component and provides a digital output signal which, ideally, should match the error protected return message packet provided by the digital processing interface 76, a digital processing circuit 96 which carries out the inverse of the error protection algorithm employed in the digital processing interface 76 and ideally provides at its output a data signal which matches the input signal provided to the digital processing interface 76, and a report/display device 98. It will be understood that the headend includes a controller (not shown) for controlling operation of the various components thereof.

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In a first mode of operation of the cable television system shown in FIG. 3, the system is used to measure the bit error rate of the transmission channel to each of the subscriber nodes. In this mode of operation, the headend controller issues a signal which is transmitted to the cable receivers, instructing the cable receivers to calculate bit error rate during a selected measurement interval, which may be defined by reference to start and stop flags included in the data stream or by reference to specific start and stop times supplied to the cable receivers by the headend.

During the measurement interval, the controller 74 calculates the bit error rate and provides an output word representative thereof. The calculated bit error rate is reported back to the headend with the cable receiver ID and a report or display is generated. The report/display device may accumulate information received from numerous cable receivers 64 and generate a report or display showing trends in bit error rate with time.

Alternatively, or in addition, the report/display device may generate a report or display showing bit error rate as a function of the locations of the cable receivers in the cable network, for example. The system operator is thereby able to determine, on a node-by-node basis, the bit error rates of the signal propagation paths between the transmitter 14 and the subscriber nodes. By comparing the bit error rates reported by different cable receivers, the cable system operator may be able to determine the location in the cable network of a particular impairment. For example, referring to FIG. 4, if the cable receivers at nodes 50C and 50D have poor transmission margin compared to the terminals at nodes 50A, 50B, 50E and 50F, indicated by high bit error rate, then it is likely that there is an impairment between the directional couplers 18_2 and $18_{2,1}$.

It will be appreciated that a test of this nature will generate a response message from each cable receiver, and accordingly it may be advantageous to instruct only selected

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cable receivers to calculate the bit error rate and provide return messages.

As noted previously, the bit error rate of the propagation path may be of limited value for monitoring degradation of the transmission quality, and it may be better to measure noise margin.

In order to measure the noise margin, i.e. the difference between the current signal-to-noise ratio and the SNR at which the bit error rate exceeds the critical bit error rate, the headend controller instructs the cable receivers (or a selected group of cable receivers) to report when the bit error rate calculated by the controller 74 exceeds the critical bit error rate. The headend controller operates the impairments generator 60 to add a noise impairment to the signal emitted by the transmitter. The noise amplitude is progressively increased, for example in stair-step fashion. In each of the cable receivers addressed by the headend controller, the controller 74 provides an output indicating the bit error rate. When the bit error rate at a given cable receiver 64 without addition of the noise impairment is sufficiently low, and the bit error rate with addition of the noise impairment exceeds the critical bit error rate, the level of impairment introduced by the impairments generator is approximately equal to the noise margin for the transmission channel from the transmitter 14 to that cable receiver. (If the impairments generator were upstream of the transmitter, the level of impairment introduced by the impairments generator would be related to the noise margin for the segment of the transmission path between the impairments generator and the cable receiver.) The cable receiver reports that the critical bit error rate has been exceeded, and includes its ID in the report. The cable system operator is thereby able to determine the noise margin to critical bit error rate on a node-by-node basis by correlating the cable receiver IDs with the level of impairment at which each cable receiver provides a report. It is, of course, necessary to correlate the report that the

critical bit error rate has been exceeded with the noise level at which the report was generated. This may be accomplished by including framing bits in the signal transmitted by the head end in the event that the cable receiver reports immediately that the critical bit error rate has been exceeded. Alternatively, the headend controller may maintain a log recording level of impairment as a function of time and the report could include a time stamp indicating the time at which the critical bit error rate was exceeded.

It may be helpful in locating system impairments in the system shown in FIG. 3, to apply an impairment to the transmission channel and observe the effect of that impairment at multiple locations simultaneously.

If there is an impairment in the trunk of the cable network or in a major branch, it is likely that many cable receivers will respond to the stair-step type of impairment and the reverse transmission system would become jammed by the message storm. This can be avoided by testing all cable receivers at relatively short intervals, with a small level of impairment. Appropriate selection of the level of impairment should ensure that relatively few cable receivers will report a malfunction or failure condition. If this indeed occurs, the operator then has confidence that the transmission channel has a reasonable margin. If there is an unexpectedly large number of return messages, the headend controller may broadcast a message to all cable receivers instructing them not to send error information but to reset and measure again. The headend then repeats the test with a lower level of impairment in order to locate the regions of the network for which the noise margin is smallest. At longer intervals, e.g. daily or monthly, the operator tests all cable receivers with a stair-step sequence of impairments preceded by a message that the cable receivers should report the result of the test only when polled. The headend then polls the cable receivers and the cable receivers respond to the poll by reporting the actual transmission margin. The polling is best done during an idle period, so as not to

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interfere with revenue generating transmissions. Since the transmission margin from the headend to each cable receiver can be inexpensively monitored, the problem of locating an impairment in the cable network is greatly simplified.

If multiple impairments exist, it can be difficult to locate the impairment responsible for a failure condition. For example, referring to FIG. 4, the reduction in transmission margin downstream of an impairment in cable segment 102 may be quite small and may be swamped by another impairment upstream in the system, e.g. in cable segment 104. Alternatively, two different impairments, e.g. in cable segments 102 and 106, may cause similar reductions in transmission margin, thus leading to the erroneous conclusion that there is a single impairment in a branch that is common to the nodes 50C and 50E, e.g. cable segment 104. If the impairments are of different types, e.g. noise and jitter, this problem can be solved by classifying the impairments.

In order to classify impairments, it is necessary to observe the effect of the impairments on symbols, as opposed to the bits used to encode the symbols.

Impairments can be classified by comparing the waveform of the signal received at the subscriber node with the waveform of the transmitted signal.

This is accomplished by using the memory 80 to capture the digital output signal of the ADC 66 during a test interval and transmitting the captured waveform back to the headend. The digital processing circuit 96 provides an output signal that matches the captured portion of the output signal of the ADC 66 and can be compared with the output signal of the transmitter 14 during the corresponding time interval, so that the effect of the impairments on symbols can be determined.

Alternatively, the captured sample of the waveform can be analyzed locally using a measurement instrument.

There are several ways in which impairments can be classified. One technique is to derive the error vector waveform and extract the spectrum of the error vector. The

presence of various impairments, such as noise, coherent distortions and spurious modulation products, can be deduced from the spectrum of the error vector. Amplitude and phase modulation impairments can be deduced from the Hilbert Transform of the error vector waveform.

The error vector waveform is derived by subtracting the signal received at the input of the cable receiver from the transmitted signal. Typically, the cable receiver will include an equalizer downstream of the ADC, often as part of the demodulator. If the equalizer is upstream of the point at which the received signal is read for storing in the memory 80, it affects the timing of the received signal and its effect must be removed in order for the received signal waveform to reflect the condition of the transmission path. This can be accomplished by using the equalizer coefficients to create a digital filter having a transfer function that is the inverse of the transfer function of the equalizer. The error vector waveform is then generated by subtracting the output waveform of the digital filter from the transmitted waveform.

Once the impairments have been classified, a particular existing system impairment is chosen for testing. The chosen impairment might be the impairment suspected of most likely causing a reduced transmission margin. The impairments generator then adds this impairment, at a sufficient level that the combined effect of the existing system impairment and the added impairment will be greater than the level previously detected for the existing impairment. Since the normal cable receiver is not calibrated for level, and there is a potential for destructive interference between the existing system impairment and the added impairment, the new aggregate level of impairment is best measured by repeating the recording and classification process and determining by how much the level of impairment has changed. If addition of this impairment causes a system failure report from the cable receiver at one subscriber node but not from the cable

receiver at another node, it can be inferred that the two nodes are affected by different impairments.

If multiple similar impairments exist simultaneously, the impairments cannot be separated by classification and the problem of locating the impairments is more complex. However, if several of the diagnostic cable receivers are instructed to record the received waveform simultaneously, signal processing of the digitized waveforms can be used to extract the separate locations of the multiple similar impairments. The cable receivers can be made to measure simultaneously by means of two mechanisms. In accordance with the first mechanism, a protocol that instructs all cable receivers (possibly just all unused cable receivers or just selected cable receivers) to tune to a particular channel and stop recording when the end of a particular data packet is received can be broadcast to all (or some) cable receivers. This method can provide robust, but relatively coarse, timing. More precise time correlation can be achieved by inserting a time mark in the broadcast waveform, and suitable signal processing can then be used to align the received waveforms with the broadcast waveform. The time mark may be inserted by transmitting a message such that there will be a transition through a selected signal level, e.g. zero volts, at a selected time, typically late in a packet.

One way of extracting the separate locations of multiple impairments has two steps. First, the error vector waveform for each subscriber node is generated by subtracting the transmitted waveform from the waveform received at each node. Second, the cross-correlation function cev (X, Y) of the error vector waveforms for two subscriber nodes 50X and 50Y is derived. Error vectors that are common to the two nodes are revealed by the cross-correlation function. When computing the cross-correlation functions along the logical path of the network from an end point (such as a subscriber node) toward the transmitter, the location of the impairment can be determined when the value of the cross-correlation function becomes smaller. For example, referring again to

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FIG. 4, and assuming that cev (E, F) indicates a common impairment and cev (A, F) indicates that the common impairment is missing, there must be an impairment between the logical locations of nodes 50A and 50E in the transmission path to node 50F. If cev (C, F) indicates a common impairment, the impairment must be between the nodes 50A and 50C. Since the only part of the network between nodes 50A and 50C that is in the transmission path to node 50F is the segment between the coupler 18_1 and the coupler 18_2, the impairment must be located there.

As a second example, if cev (C, D) indicates a common impairment and cev (A, D) indicates that the common impairment is missing, there must be an impairment logically located between node 50A and the coupler $18_{2,1}$. This implies that the impairment must be located between the directional coupler 18_1 and the coupler $18_{2,1}$. If cev (D, E) indicates that the common impairment is missing, the impairment is not between directional coupler 18_1 and the directional coupler 18_2, and so the impairment must be between the directional coupler 18_2 and the coupler $18_{2,1}$.

It is necessary to carry out the tests using the impairments generator with minimal disturbance to the revenue generating communication traffic. This is accomplished by adding the impairments only to selected packets or segments of data having a relatively low value with respect to the revenue generating communication traffic.

Most digital video transmission systems utilize the MPEG transport stream. The MPEG transport stream is composed of several MPEG elementary streams which are multiplexed to produce the MPEG transport stream. Stuffing bits are inserted in order to create the constant bit rate MPEG transport stream. It is important that the impairment should degrade only the stuffing bits or other non-customer (i.e. non-payload) bits. Since the impairments are added in the analog domain (in the case of the impairments generator being downstream of the transmitter), the impairments are applied to the transmitted symbols, in which several bits are

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encoded. Interleaving in constructing the transmitted data stream may result in a symbol containing bits derived from multiple elementary streams. Accordingly, it is necessary to detect when a symbol consists entirely of non-customer bits and degrade only those symbols. The cable receiver 64 can be instructed to pick out a degraded symbol by including a private data message in the MPEG transport stream. The message might, for example, instruct the cable receiver to pick out a numerically specified symbol after the next sync byte after the Program Clock Reference for a specified Program ID. It will be appreciated that the impairments could be added in the digital domain, e.g. in the digital processing interface 8. In this case, while the impairments are added in the digital domain, they are nevertheless a description of the desired analog waveform, so the impairments are of an analog nature.

An alternative is to include the impairment at a time when all of the payload bits are of relatively low perceived value. For example, the operator might include a special announcement simultaneously on all of the program streams contained in a single transmitted channel. The time of transmission of this announcement is chosen so that the balance between the loss of advertising revenue and the benefit of announcing the quality enhancement efforts is optimized. The announcement might indicate that the system operator is testing the network to ensure that subscribers receive the best possible quality, and thereby has some value. In either case, it is necessary to ensure that the symbol that is degraded does not contain customer bits or that the probability of causing an uncorrectable error is acceptably low.

A cable television network may be used to provide bidirectional voice communication, similarly to the public telephone network. In this case, the subscriber's telephone instrument is not connected to the public telephone network but is connected through a suitable adapter to the television cable network. The adapter digitizes the subscriber's

outgoing voice message and employs it to modulate a carrier, and similarly detects and converts to analog form an incoming digitized voice message. The headend is connected to the telephone instrument of the other party to the call through another network, which might be the public telephone network or include another cable distribution system. In either case, voice messages are transmitted bidirectionally between the subscriber node and the headend over the cable network by digitizing the voice messages and modulating a carrier with the digitized voice messages. The test method described herein can be used for testing a transmission channel used for voice transmission by providing a diagnostic function in the equipment at the subscriber node. The diagnostic function may be added to the functions performed in the subscriber's telephone/cable adapter or may alternatively be provided by a separate diagnostic receiver.

Bidirectional voice transmissions tend to be bursty, but excessive latency in response may be objectionable to the user. Accordingly, test packets should only be used during transmission if they are short enough that they will not cause excessive latency. Alternatively, since voice transmissions tend to be relatively short and have a protocol for starting and finishing each transmission session, test packets may be sent when setting up a call, tearing down a call, or during idle times.

FIG. 5 illustrates schematically a public telephone network including a node 110, such as a central office or fiber node, and subscriber lines 114 extending from the central node 110 to respective subscriber nodes 118. Analog voice traffic may be carried on the lines 114. Digital data may also be transmitted over the subscriber lines. For example, the central node may be connected to an internet service provider and provide for data transmission between a subscriber node and the ISP. In accordance with an xDSL protocol, such as ADSL (asynchronous digital subscriber line), the digital data is used to modulate one or more carriers, each having a frequency outside the audio range and

the digital data can then be transmitted concurrently with the analog voice traffic. In this case, the central node includes an xDSL transceiver and the subscriber node also includes an xDSL transceiver, for transmitting data between the central node and the subscriber node using the ADSL protocol.

The invention may be used to test the subscriber lines 114 to ensure that the digital data can be transmitted error free. At the subscriber node, the xDSL transceiver includes, or is provided with, a diagnostic receiver which operates similarly to the diagnostic cable receiver illustrated in FIG. 3. This provides a technique for detecting impairments in the transmission channel from the central node to individual subscriber nodes before the transmission channel is degraded to such an extent that error protected data packets cannot be recovered at the subscriber node. The other functions described with reference to FIGS. 3 and 4, such as transmission of messages to a central location and remote classification of impairments, apply to the system described with reference to FIG. 5.

In the case of data transmission, it is much simpler to include impaired packets in the transmission because data transmissions are usually bursty. By using a broadcast protocol, many subscriber lines can be tested in parallel by sending test packets to all subscriber nodes simultaneously. When testing an individual subscriber line, it is necessary to control operation of the impairments generator to ensure that the packet address will not be impaired, so that the subscriber node can correctly identify a packet intended for it. Rather, only the data inside the packet should be impaired.

It will be appreciated that the invention is not restricted to the particular embodiments that have been described, and that variations may be made therein without departing from the scope of the invention as defined in the appended claims and equivalents thereof. For example, although the description of FIGS. 3 and 4 refers to the

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return path from the subscriber node 50 to the headend 48 as being the cable that is used for transmission from the headend to the subscriber node, it may instead be implemented by another medium, such as the public switched telephone network.

Claims

1. A method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising:

(a) generating an error protected data packet for transmission over the transmission path,

(b) impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested,

(c) transmitting the data packet over the transmission path,

(d) receiving the data packet at the receiver, and

(e) determining whether the received data packet is error free.

2. A method according to claim 1, further comprising, if the transmission path is not error free, transmitting a message from the receiver to the transmitter.

3. A method according to claim 1, wherein step (c) comprises progressively increasing the extent to which the transmission path is impaired.

4. A method according to claim 1, wherein the network has a plurality of receivers and digital data is transmitted to the receivers over respective transmission paths, step (b) comprises transmitting the data packet to the receivers over the respective transmission paths, step (d) comprises receiving the data packet at each receiver, and step (e) comprises determining at each receiver whether the received data packet is error free.

5. A method according to claim 4, further comprising, if the transmission path to a selected receiver is not error

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free, transmitting a message from the selected receiver to the transmitter, and analyzing messages received at the transmitter.

6. A method according to claim 4, wherein the method comprises detecting receivers that report higher than average error rates and comparing the transmission paths to the respective receivers in a manner such as to derive information from the receivers that report higher than average error rates.

7. A method according to claim 4, wherein step (c) comprises progressively increasing the extent to which the transmission path is impaired and the method further comprises:

transmitting a message from a receiver to the transmitter if the transmission path to that receiver is not error free, and

correlating messages received at the transmitter with the extent to which the transmission path is impaired.

8. A method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising:

(a) generating an error protected data packet for transmission over the transmission path,

(b) transmitting the data packet over the transmission path as an analog signal,

(c) receiving the analog signal at the receiver,

(d) recording the analog signal received at the receiver, and

(e) transmitting the record of the analog signal to a remote location for analysis.

9. A method according to claim 8, wherein step (e) comprises transmitting the record of the analog signal to the transmitter for analysis.

10. A method according to claim 8, wherein step (d) comprises digitizing the analog signal and the method further comprises deriving digital data from the digitized signal, forming a data packet from the digital data derived from the digitized signal, transmitting the data packet to the transmitter as an analog signal, digitizing the analog signal received at the transmitter, and processing the digitized signal at the transmitter.

11. A method according to claim 10, wherein the step of processing the digitized signal at the transmitter comprises deriving the error vector waveform for the transmission path to the receiver.

12. A method according to claim 8, wherein the network has a plurality of receivers and digital data is transmitted to the receivers over respective transmission paths, step (d) comprises digitizing the analog signal at each receiver, and the method further comprises deriving digital data from the digitized signal at each receiver, forming data packets at the respective receivers from the digital data derived from the digitized signal at each receiver, transmitting the data packets to the transmitter as analog signals, digitizing the analog signals received at the transmitter, and processing the digitized signals at the transmitter, and the step of processing the digitized signal at the transmitter comprises deriving the error vector waveforms for the transmission paths to at least first and second receivers and deriving the correlated error vector function for the transmission paths to the first and second receivers.

13. A method according to claim 8, wherein the network has a plurality of receivers and digital data is transmitted

to the receivers over respective transmission paths, and the method comprises deriving digital data from the digitized signal at each receiver, transmitting the digital data to the transmitter, and analyzing data received from multiple receivers to extract the locations of uncorrelated impairments.

14. A method according to claim 8, comprising processing the digitized signal to classify an impairment in the transmission path and testing the transmission margin of the transmission path with respect to the impairment by impairing the transmission path using that impairment.

15. A method according to claim 8, further comprising impairing the transmission path to a selected extent upstream of a transmission path segment to be tested.

16. A method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate at least one carrier and impressing the modulated carrier on the network, said method comprising:

generating an error protected data packet for transmission over the transmission path,

impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested,

transmitting the data packet over the transmission path,

receiving the data packet at the receiver, and

counting bit errors in the received data packet.

17. A method of operating a digital data distribution network having a transmitter and a receiver, wherein digital data is transmitted in error protected packets from the transmitter to the receiver over a transmission path by employing the digital data to modulate a carrier and

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impressing the modulated carrier on the network, said method comprising:

(a) generating an error protected data packet for transmission over the transmission path,

(b) impairing the transmission path to a selected extent upstream of a transmission path segment that is to be tested,

(c) transmitting the data packet over the transmission path as an analog signal, and

(d) receiving the analog signal at the receiver.

18. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by reducing its signal-to-noise ratio.

19. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by reducing its frequency response.

20. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by reducing its phase response.

21. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by reducing its impulse response.

22. A method according to claim 17, wherein the step of impairing the transmission path comprises impairing the transmission path by introducing phase noise or jitter.

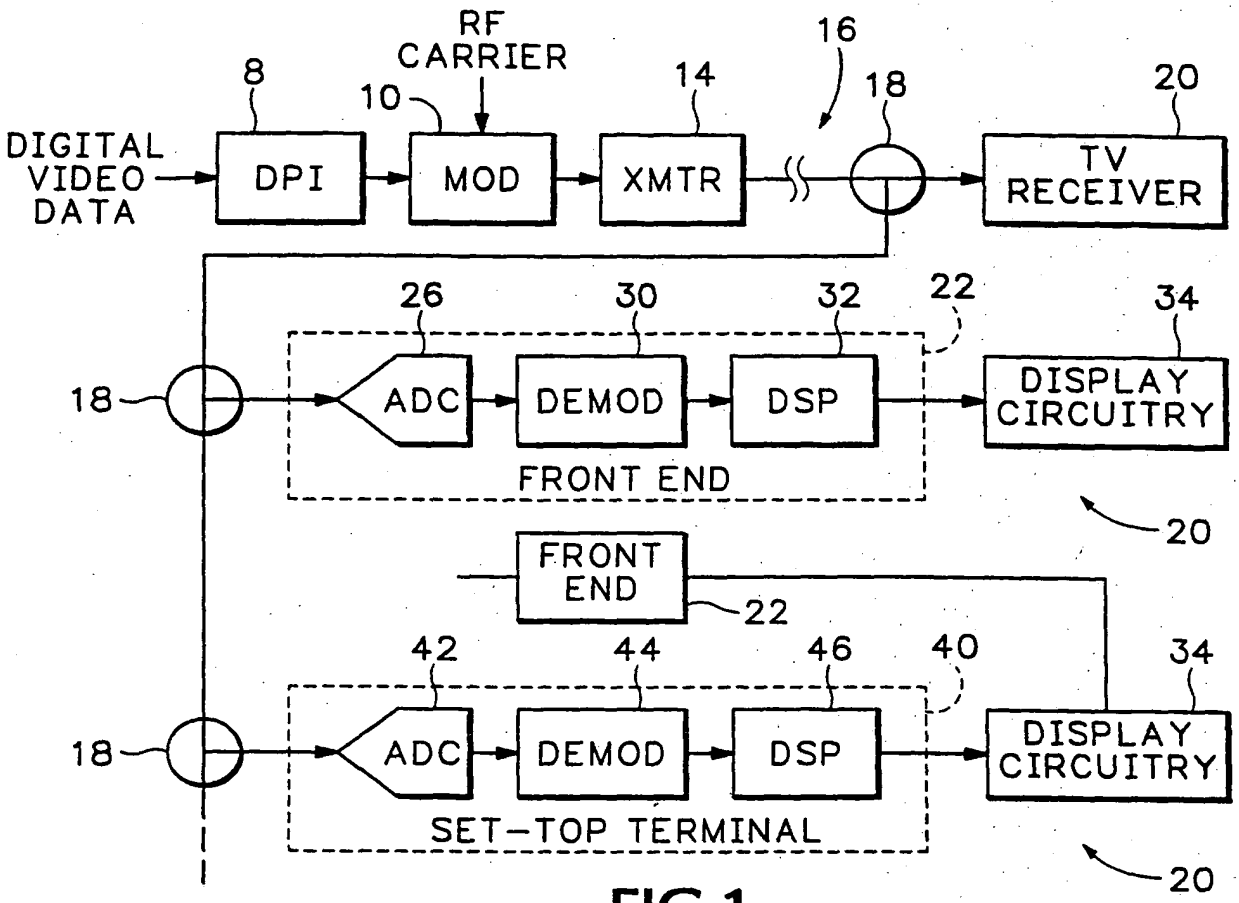

FIG.1

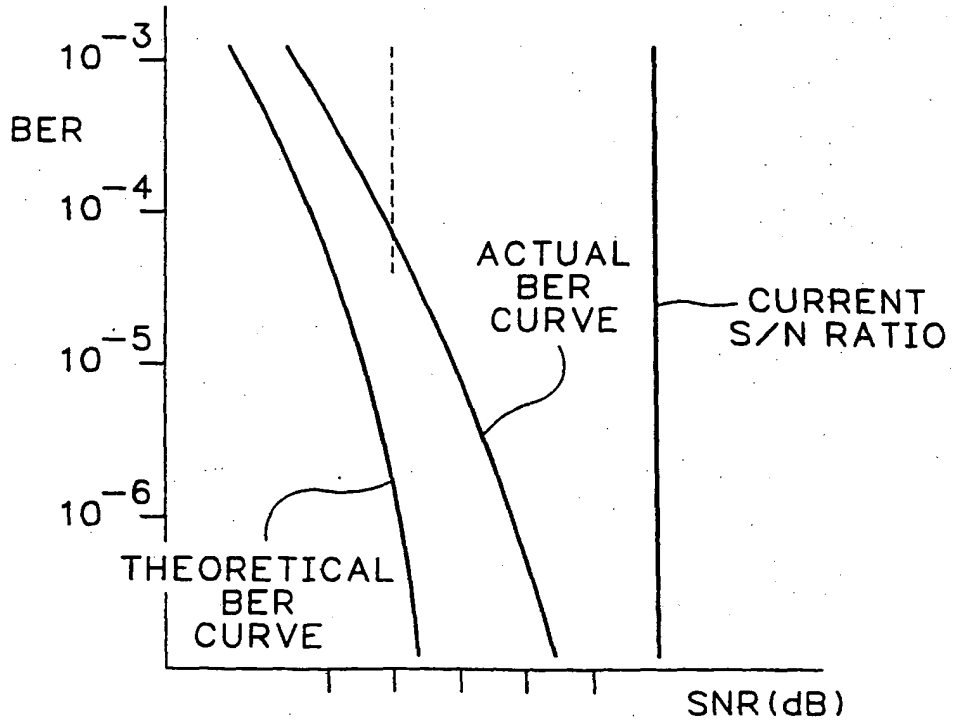

FIG.2

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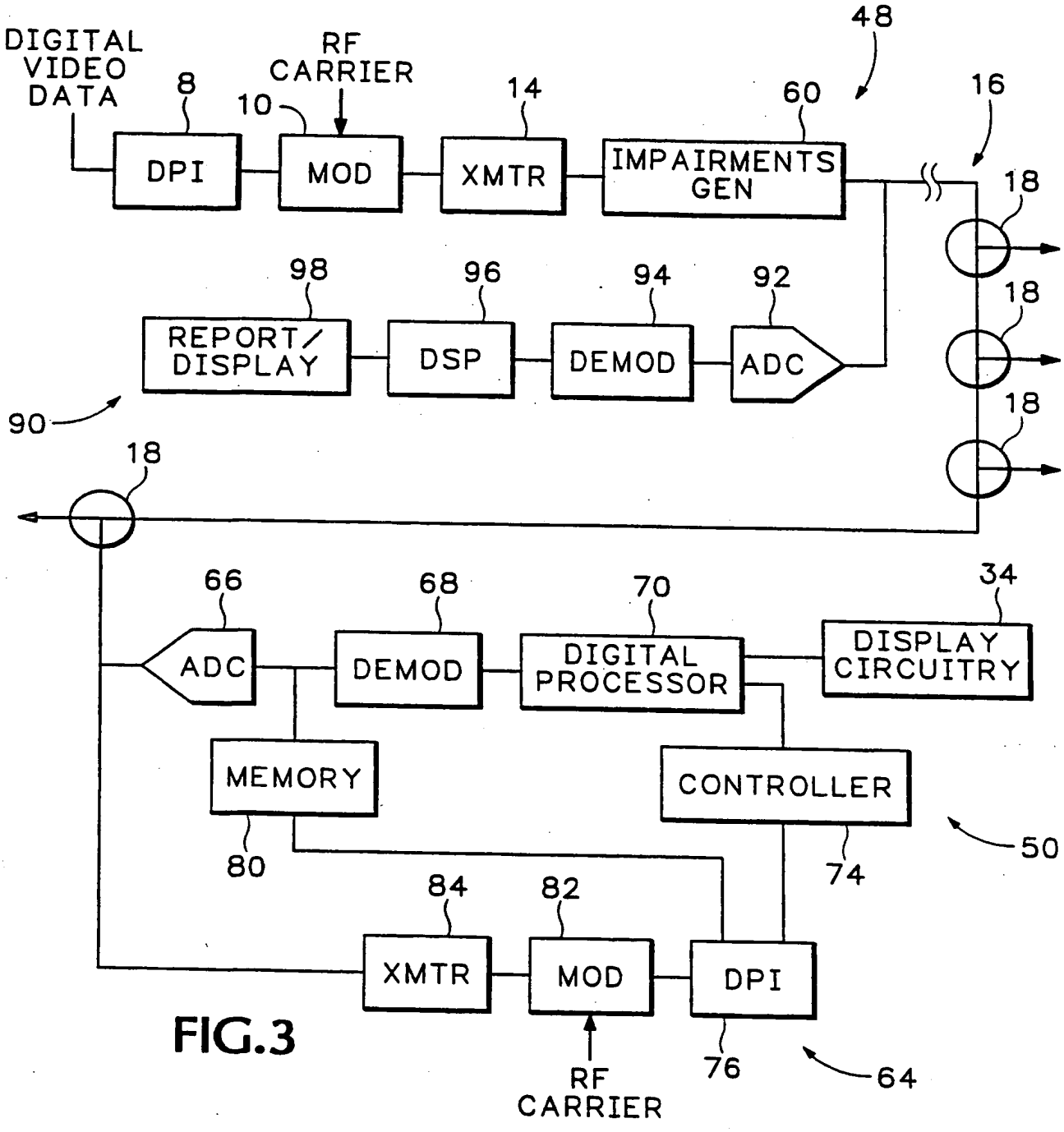
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REPORT/ DISPLAY
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FIG.3

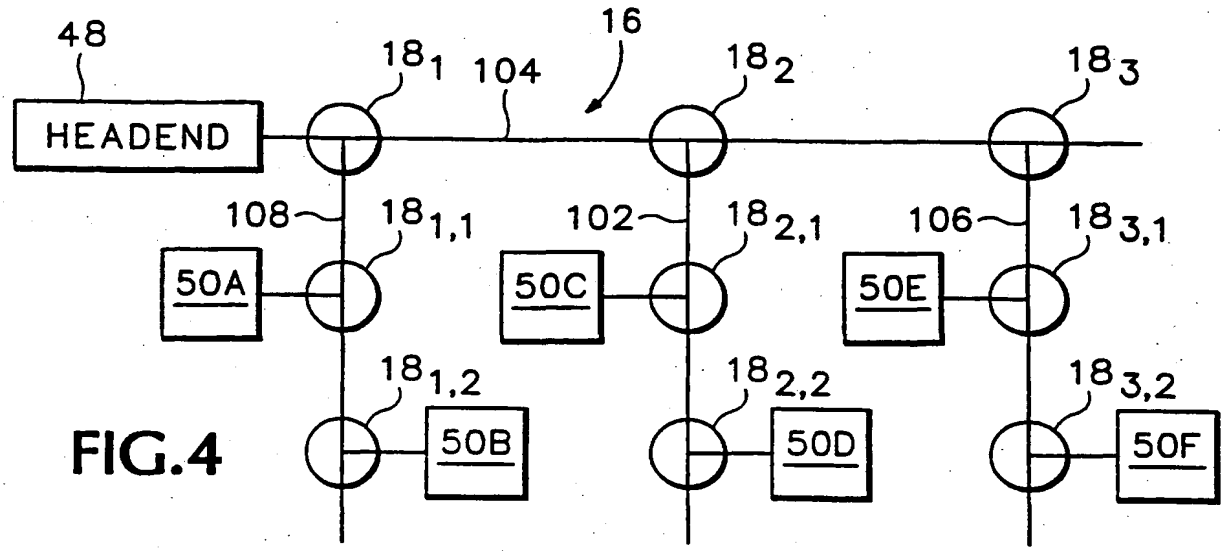

FIG.4

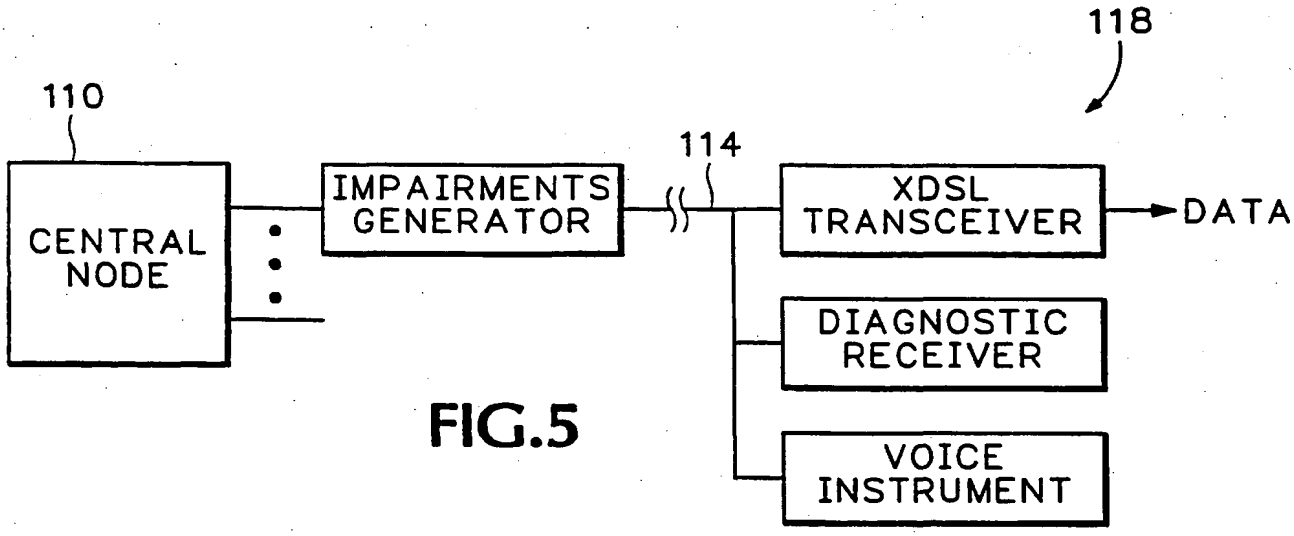

FIG.5

BNSDOCID: <WO 9926375A2 I >

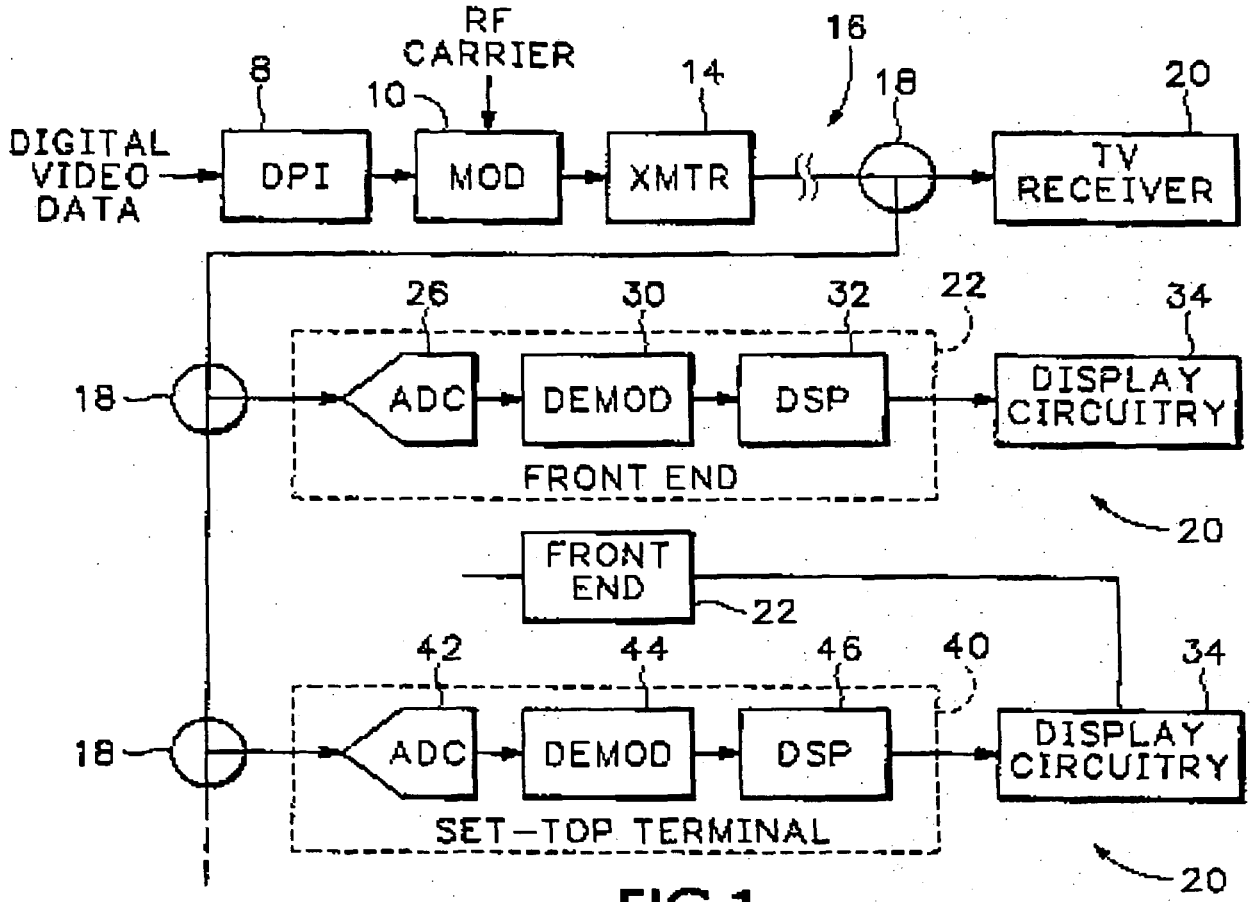

FIG.1

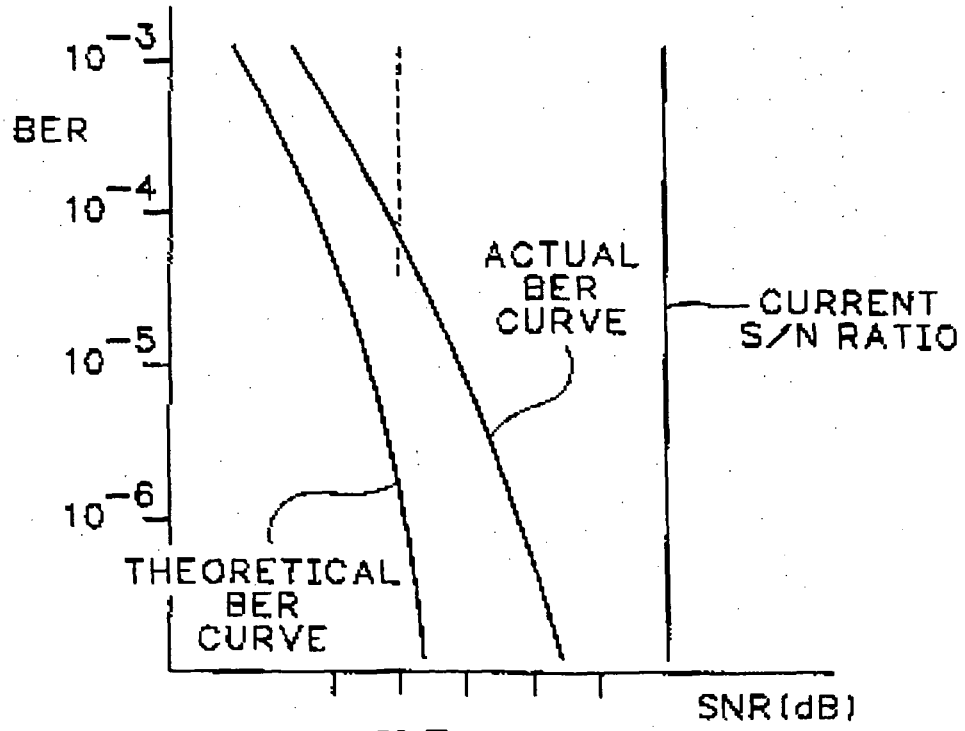

FIG.2

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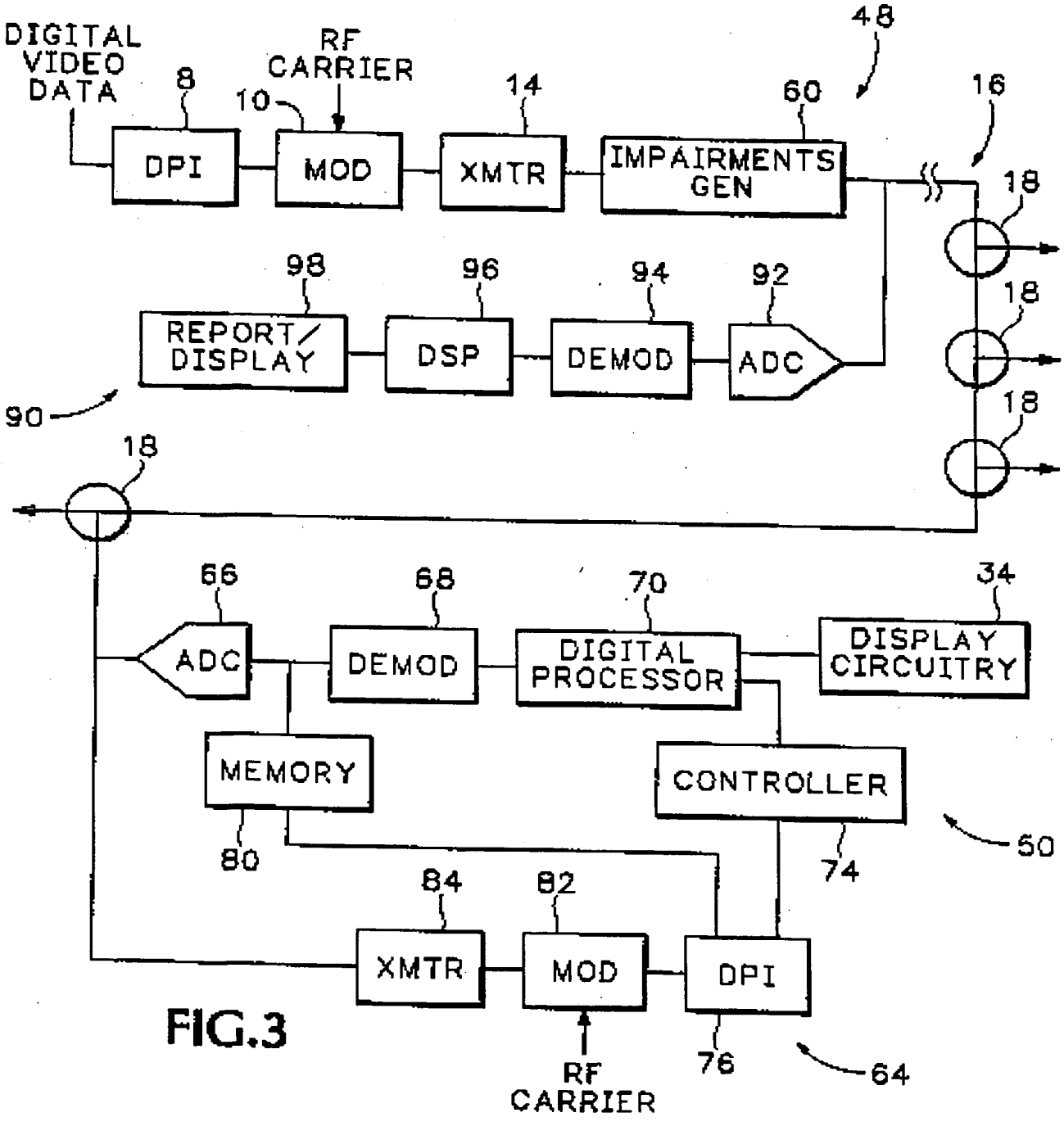
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ADC
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FIG.3

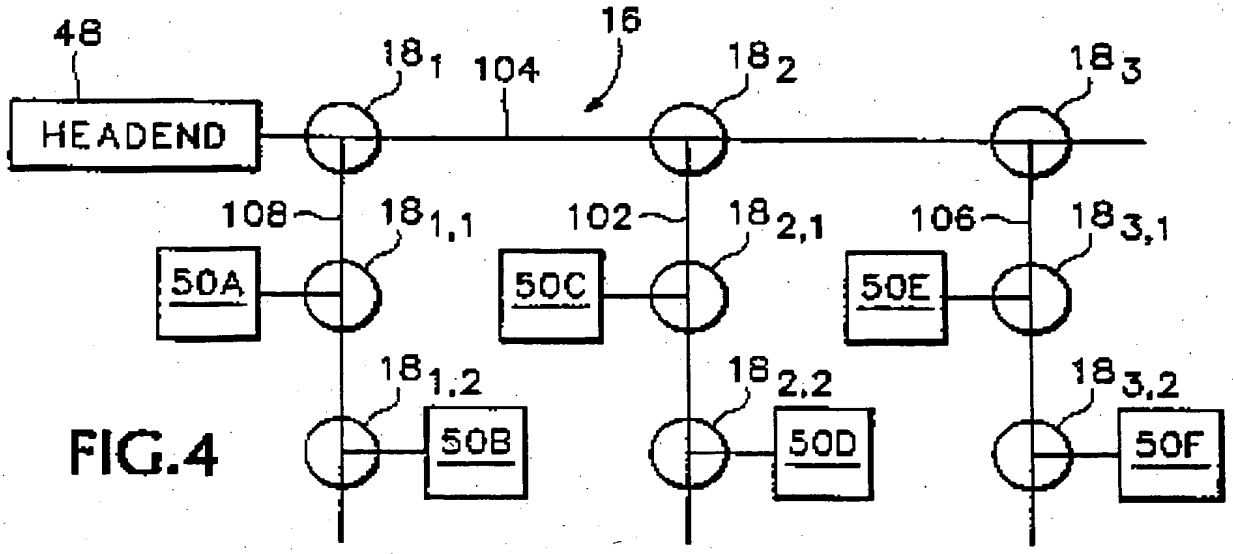

FIG.4

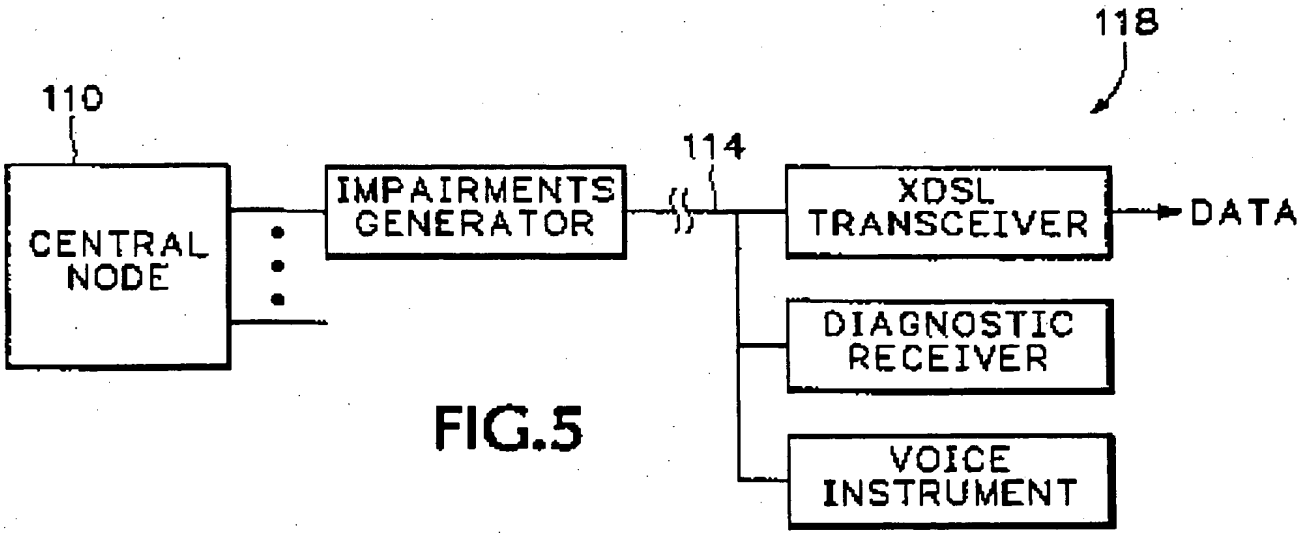

FIG.5

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(81) Designated States: CA, CN, KR, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

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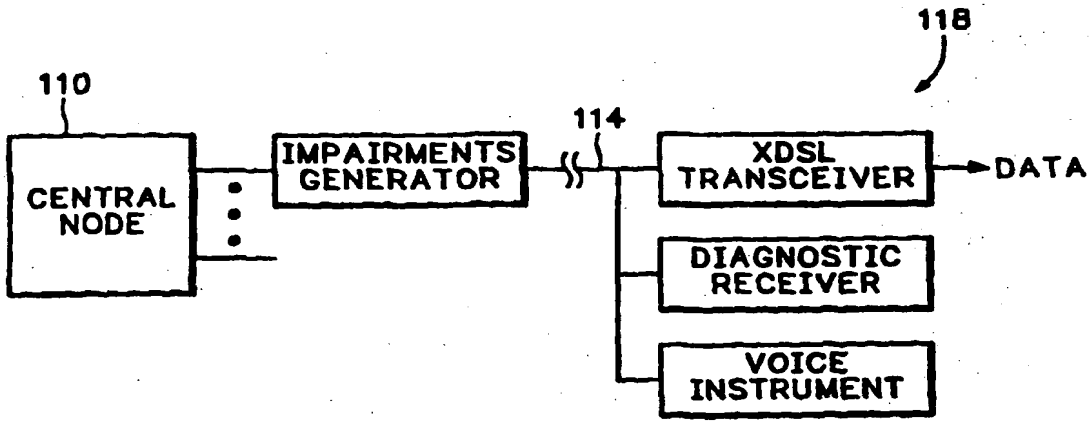

(57) Abstract

Digital data in error protected packets is used to modulate a carrier and the modulated carrier is impressed on a digital data distribution network for transmission to a receiver over a transmission path. In order to monitor operation of the data distribution network, the transmission path is impaired to a selected extent upstream of a transmission path segment that is to be tested and an error protected data packet is transmitted over the transmission path to the receiver. A determination is made at the receiver whether the received data packet is error free, and, if not, a message is transmitted from the receiver to the transmitter.

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 98/23336

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L1/24 H04L1/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04L H04N H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 655 068 A (OPOCZYNSKI ADAM) 5 August 1997 see abstract; figure 9 see column 2, line 33 - line 58 see column 4, line 44 - line 58 see column 5, line 6 - line 22 see column 5, line 47 - line 51 see column 8, line 30 - line 42 ---	1-7, 16-18
Y	US 4 384 354 A (CRAWFORD THOMAS M ET AL) 17 May 1983 see abstract; figure 6 see column 2, line 56 - column 3, line 16 see column 4, line 36 - line 62 see column 6, line 61 - column 7, line 10 see column 7, line 14 - line 33 see column 12, line 60 - line 62 see column 13, line 19 - line 29 --- -/--	1-7, 16-18

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
27 May 1999	09. 08. 1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Papantoniou, A

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BNSDOCID: <WO___9926375A3_I_>

INTERNATIONAL SEARCH REPORT

International Application No
PCT/U[illegible] 98/23336

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 934 224 A (DULANEY ERNEST N ET AL) 20 January 1976 see abstract; figure 1 see column 3, line 13 - line 27 see column 3, line 40 - line 62 see column 4, line 5 - line 11 see column 4, line 53 - line 63 see column 5, line 17 - line 21 see column 7, line 20 - line 28	8-10
X	EP 0 452 124 A (INLAND STEEL CO ;NCR CO (US)) 16 October 1991 see abstract; figures 2,4 see column 2, line 10 - line 13	8,9
A	see column 3, line 17 - line 21 see column 4, line 48 - line 51	10
A	US 5 608 728 A (MAZZA-BRENNAN CYNTHIA ET AL) 4 March 1997 see abstract see column 2, line 23 - line 49 see column 4, line 17 - line 31 see column 5, line 23 - line 32	8-14
A	EP 0 905 940 A (LUCENT TECHNOLOGIES INC) 31 March 1999 see abstract; figure 4 see column 3, line 38 - line 43 see column 4, line 23 - line 33 see column 5, line 28 - line 43	8-14
A	US 5 060 226 A (GEWIN ROBERT E ET AL) 22 October 1991 see abstract; figure 2 see column 3, line 52 - column 4, line 3 see column 7, line 63 - column 8, line 18	8-10
A	US 3 910 322 A (HARDESTY JR SAMUEL J ET AL) 7 October 1975 see abstract see column 1, line 54 - column 2, line 9 see column 2, line 29 - line 36 see column 3, line 41 - line 60 see column 4, line 22 - line 29 see column 6, line 49 - line 60	8-10

7

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BNSDOCID: <WO___9926375A3_I_>

INTERNATIONAL SEARCH REPORT

Interr...onal application No.
PCT/US 98/23336

B x I Observations wher ertain claim w re found unsearchabl (Continuation f item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

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FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-7, 16-22

Group 1 relates to the operation of a data distribution network whereby the transmission path is impaired upstream of a segment of a transmission segment that is to be tested. Subsequently, it is determined whether transmitted error protected packets are error free.

2. Claims: 8-15

Group 2 relates to the operation of a data distribution network whereby the receiver records the received transmitted error protected packets (analogue signal) which are then sent back to a remote location (that can be the transmitter) for analysis.

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